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An ultrasound model to calculate the brain blood outflow through collateral vessels: a pilot study

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There are figures in this document, which show veins and the flow rate of each, in the collateral networks and main outflow paths for blood in the necks of Healthy Control subjects and CCSVI subjects.

The diagrams in Dr. Zamboni's ultrasound model look like the resistor networks that first year electricity students must solve. They use mostly simple formulas like Ohm's Law (1827), and usually without Calculus, using at most the quadratic formula.

If you draw the parallel to electricity, which has often been considered a fluid, the diagram in Dr. Zamboni's paper is directly matched by the corresponding circuit diagram, with resistors analogous to veins or arteries, electrical current in copper wires analogous to blood flow rate in veins or arteries, and resistance to electrical current analogous to resistance to venous or arterial blood flow. There are blood flow rate values on Dr. Zamboni's diagram, as measured in the study.

There is another Law, which has a similar equation, Poiselle's Law (1846-1849), for three inversely related quantities, with different terminology. The equation for Ohm's Law says V=IR, and the other says P=FR. The two equations are identical relationships, but the quantities have different names in different units, because of the differing fluids.

Fluid mechanics experts, dealing with matter in fluid form, call P, or Pressure, by the same name that people who know electricity call Voltage. Voltage, in electrical discussions, was formerly called pressure. The other two analogous quantities are called by the same or similar names, but if you look at the units of each you will see they describe the same fluid characteristics.

There are other physical properties for both fluids, and we have different names for them, like turbulence in one case, and static discharge in the other. Other examples are viscosity in fluid mechanics and capacitance in electricity. They are all physical properties of two very different fluids. The fluids are composed of moving particles, sometimes of only molecules, or ions of the medium alone, in liquid matter in fluid mechanics. Sometimes, as in blood, the particles are cells, in a medium of plasma or water. In electricity they make up a current of charged electrons, in a conducting wire, usually of copper,

Poisselle's Law in fluid mechanics has direct analogy with Ohm's Law in electricity, which was formerly considered a fluid. That law says P=FR. That means Pressure=Resistance x Flow Rate. This is not news to anyone familiar with fluid dynamics, nor is Ohms Law unfamiliar to those familiar with electricity.

“Electricity was originally understood to be a kind of fluid. This “Hydrolic Analogy” is still conceptually useful for understanding circuits. This analogy is also used to study the frequency response of fluid mechanical networks using circuit tools, in which case the fluid network is termed a Hydraulic Circuit.

Poiseuille's law corresponds to Ohm’s law for electrical circuits ($V = IR$), where the pressure drop ΔP is analogous to the voltage V and volumetric flow rate Φ is analogous to the current I. Then the resistance to flow R is defined as

$$R = \frac{8\eta\Delta x}{\pi r^4}.$$

This concept is useful because the effective resistance in a tube is inversely proportional to the fourth power of the radius. This means that halving the radius of the tube increases the resistance to fluid movement by a factor of 16.”

http://en.wikipedia.org/wiki/Hagen-Poiseuille_equation#Electrical_circuits_analogy

The viscosity is **η**, **Δx** is the length of the pipe, and **r** is the pipe’s radius.

The quantities involved in Poiselle’s and Ohm’s Laws are all in SI base and derived units. See [URL]http://physics.nist.gov/cuu/Units/[/URL]

Ohm’s Law involves Current, directly analogous to Volume Flow Rate in Poisilles’s Law concerning laminar fluids of Viscosity **η** in a pipe of length **Δx**, and radius **r**.

Viscosity of blood should not be hard to measure from a sample.

The units of these laws fluid mechanics are all from SI, or from geometrically derived lengths.

Some of the principal scientists involved in elaborating the laws of electricity, used the Ohm/Poiselle duality to elucidate their efforts in electricity.

Maxwell (1871-39) and Kirchoff (1824-87) for electricity, and Darcy (1803-58) and Weissbach (1806-71) used the fluid mechanics principle. Both Johannes Diderik van der Waals in 1873 and Richard Sears McCulloh (1818-94) used the analogy, because both are simple inverse relations describing energy conversion between kinetic and potential, using the energies and positions of fluids. The particles of electric fluids are electrons. They possess charge, which has a binary polarity, positive and negative. Electrons and blood cells both have mass.

For discussions of the above scientists and their discoveries, see Wikipedia.

Possessing two of the three values: flow rate and resistance, since the equations says P = FR, the solution can be calculated for pressure.

Resistance, R, and Pressure, P, are the unknowns in Dr. Zamboni's model and the diagram of the collaterals. Blood fluid resistance is measureable with the minimal invasion of a needle and syringe to measure a small sample of the blood's viscosity **η**, at body temperature. Fluid Resistance, **R**, can be found using the Laws of Poiselle, over a straight length of pipe-shaped blood vessel, length **Δx**, of Radius **r**.

This technique may provide fairly accurate single-point-based measurements, giving a local value of P, the blood Pressure, without taking measurements at two points. The pressure drop across a stenosis might require verification of the straightness of the vessel between the two ends. The non-constant cross-sectional area over a stenosis will show in the P measurements at the two ends.

Knowing F and R we can multiply and get Pressure. Dr. Zamboni's diagram, or a similar one, may be further detailed. That may elucidate any flow problems.

A computer-based device or machine, which acts like a volt-ohm meter, but for arterial or venous blood, measuring all three quantities: F, R, and P, can be envisioned. The operator would take a blood sample, measure and record the blood sample's fluid resistance, saving the value in the machine. Using a Doppler ultrasound probe or other means, flow rate can be directly measured. Then the computer or machine would do the multiplication and give the value of all three quantities, pressure, resistance, and flow rate.

In fact, carbon resistors (R), a battery (P) and a galvanometer (I or F) could do the calculation of any one of the three, from analog inputs of the values of the other two, in the same manner as an analog voltmeter does today. A computer could substitute for the voltmeter and accomplish the same.

These are only approximations: the pipes are not ideal in blood vessels. They have curvature, which affects Resistance via turbulence. Their cross-section is not circular but ellipsoid, and various other shapes, due to flattening.

For purposes of solving the unknowns of Dr. Zamboni’s model, they may suffice.